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Stock Assessments and Biological Investigations of Kokanee *(Oncorhynchus nerka)* in Cowichan Lake, British Columbia 1984 - 1987

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STOCK ASSESSMENTS AND BIOLOGICAL INVESTIGATIONS OF KOKANEE (*Oncorhynchus nerka*) IN COWICHAN LAKE, BRITISH COLUMBIA 1984 - 1987

by

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ABSTRACT

Rutherford, D. T., C. C. Wood, and J. R. Candy. 1988. Stock assessments and biological investigations of kokanee (Oncorhynchus nerka) in Cowichan Lake, British Columbia, 1984-1987. Can. MS Rep. Fish. Aquat. Sci. 1995: 35 p.

Cowichan Lake has a maximum depth of 160 m and surface area of 6360 ha. Annual hydroacoustic and trawl surveys conducted on Cowichan Lake from 1984 to 1987 indicated a kokanee population of 3.4 to 5.1 million fish (mostly juveniles) with densities ranging from 540-822 fish/ha. Kokanee were far more numerous than any other fish species in the limnetic zone. They matured at age 3 at lengths ranging from 153 to 172 mm. Males were more numerous than females in all five samples of juveniles examined from three consecutive years; the proportion of males ranged from 0.53 to 0.74. A higher proportion of large kokanee (age 1+ and 2+) were caught in seine catches than in midwater trawl catches, which suggests that the two gear types select for different size classes. Age 1+ and 2+ kokanee from Cowichan Lake showed some ability to osmoregulate in salt water; plasma sodium levels varied widely from 172 to 258 mmol/L (mean=197 mmol/L) among 27 fish held for 24 h at a salinity of 23°/... Biochemical genetic comparisons at five polymorphic loci suggest that Cowichan Lake kokanee are more similar genetically to the neighbouring Cheewhat Lake sockeye population than to the other Vancouver Island stocks sampled.

RÉSUMÉ

Rutherford, D. T., C. C. Wood, and J. R. Candy. 1988. Stock assessments and biological investigations of kokanee (Oncorhynchus nerka) in Cowichan Lake, British Columbia, 1984-1987. Can. MS Rep. Fish. Aquat. Sci. 1995: 35 p.

La profondeur du lac Cowichan atteint 160 m au maximum et sa superficie, 6360 ha. D'après les recensements effectués chaque année dans le lac Cowichan de 1984 à 1987 soit à la palangre, soit avec des moyens de détection hydroacoustique, la population de kokanis se situerait entre 3,4 et 5,1 millions de poissons (pour la plupart juvéniles) avec des densités variant de 580 à 822 poissons/ha. Dans la zone limnétique, les kokanis étaient bien plus nombreux que n'importe quelle espèce. Ils atteignaient leur maturité à l'âge 3, leur longueur variant à ce moment-là entre 153 et 172 mm. Les mâles étaient plus nombreux que les femelles dans les cinq échantillons de spécimens jeunes examinés au cours de trois années consécutives; la proportion de mâles variait de 0,53 à 0,74. On capturait plus de grands poissons (âge 1+ et 2+) à la senne qu'à la palangre à moyenne distance, ce qui indique que la taille des poissons capturés varie en fonction de chacun de ces deux types d'engin. Les poissons du lac Cowichan âgés de 1+ ou 2+ étaient quelque peu capables d'osmo-régulation dans de l'eau salée; les concentrations de sodium dans le plasma variaient beaucoup, allant de 172 à 258 mmol./L (moyenne = 197 mmol./L) chez 27 spécimens gardés pendant 24 h à un degré de salinité de 23°/...
Si l'on en juge par les comparaisons génétiques biochimiques effectuées à cinq locus polymorphiques, les kokanis du lac Cowichan ressemblent plus, génétiquement, à la population de saumons nerka du lac Cheewat, situé dans le voisinage, qu'aux autres stocks de l'île de Vancouver, qui ont été échantillonnés.

INTRODUCTION

Three forms of Oncorhynchus nerka have been distinguished in British Columbia: the anadromous form; a non-anadromous, lake dwelling form ("the kokanee") and the non-anadromous progeny of anadromous sockeye ("residual sockeye") (Ricker 1938). Both kokanee and anadromous sockeye have been reported within the Cowichan River system (Neave 1949). Non-anadromous kokanee are relatively abundant in Cowichan Lake whereas anadromous sockeye are very uncommon. From 1885-1904 attempts were made to establish an anadromous sockeye run to Cowichan Lake by transplanting eggs from anadromous Fraser River sockeye stocks but this was apparently unsuccessful (Aro 1979).

To our knowledge there are no published reports of anadromous sockeye occurring in Cowichan Lake or its tributaries. However, two anadromous sockeye were sighted in Robertson River, a tributary of Cowichan Lake, on December 12, 1968 during surveys of spawning escapements (Bob Hungar, Pacific Biological Station, Nanaimo, B.C., V9R 5K6 pers. comm.). Because Cowichan Lake is visited frequently by sports fishermen, boaters and residents, an anadromous sockeye run to the lake would have to be extremely small to have remained undetected. This apparent absence of anadromous sockeye is puzzling since there are no obvious barriers to seaward migration in the Cowichan River. Furthermore, the lake supports a sizable anadromous coho salmon (O. kisutch) population and a fish ladder was constructed in 1956 to facilitate passage over Skutz Falls which might obstruct migration during unfavorable water flows.

This report summarizes information on the occurrence and population biology of juvenile O. nerka obtained during hydroacoustic and trawl surveys from 1984 to 1987. These surveys were designed to determine the abundance of juvenile O. nerka in Cowichan Lake and to provide background data for evaluating the potential for either establishing an anadromous sockeye run in the system or increasing the productivity of the existing kokanee population.

Population densities of juvenile O. nerka were estimated using hydroacoustic and midwater trawl sampling techniques. In addition, live kokanee were obtained using a purse seine to investigate the feasibility of tagging wild kokanee and forcing seaward migration as previously attempted with hatchery - raised kokanee (Foerster 1947). Preserved kokanee were examined for biological and biochemical genetic (electrophoretic) attributes to shed light on their population biology and their relationship to neighbouring anadromous sockeye populations.

STUDY AREA

Cowichan Lake is a clearwater lake located on the southeast portion of Vancouver Island at 48°50' N. Latitude X 124°15' W. Longitude. It is drained to the east via the Cowichan River to the Strait of Georgia (Fig. 1).

Cowichan Lake experiences a mild, moist climate; average winter and summer air temperatures for the region are 2.1°C and 18.6°C respectively with an annual rainfall of 961 mm (Bell and Kallman 1976).

Cowichan Lake is 31 km long and has a surface area of 6360 ha with a maximum depth of 160 m. Six main streams and several other smaller streams feed Cowichan Lake, draining a total watershed area of 61,662 ha. The shoreline consists of commercial and private development, precipitous rock, gravel beaches and marsh areas. A water level control dam is located at the lake outlet but it is not a barrier to fish in the Cowichan River. However, there are two partial obstructions, one at Skutz Falls and the other at Marie Canyon, 20.5 and 15.0 km below the lake's outlet, respectively. Skutz Falls has a drop of less than 5.5 m over a run of 90 m and Marie Canyon has a drop of 3 m over a 30 m distance. These falls do not prevent access of coho and chinook (O. tshawytscha) to Cowichan Lake. A fish ladder past Skutz Falls was constructed in 1956 by the Department of Fisheries and Oceans (DFO) to facilitate upstream migration. Several other salmonid species, both anadromous and non-anadromous, utilize Cowichan Lake including rainbow trout and steelhead trout (Salmo gairdneri), cutthroat trout (Salmo clarki), dolly varden (Salvelinus malma), brown trout (Salmo trutta) and brook trout (Salvelinus fontinalis) (Idyll 1942; Neave 1949; Carl 1953; Bell and Kallman 1976).

METHODS

Lake measurements

Lake bathymetry and maximum depth were determined from echo-soundings using a Simrad EYM echo sounder. Depth was measured along 22 transects across the lake spaced at roughly equal intervals down the length of the lake. The bathymetric map (Fig. 2) was drawn following the method outlined by Rutherford et al. (1986).

Lake and watershed areas were determined from a 1:50,000 National Topographic Series map (Province of British Columbia, Surveys and Mapping Branch). Areas were measured three times using a high resolution digitizing table and the means of three measurements are reported here. The stratum area (Table 1) corresponding to the midpoint of a depth interval is the difference between lake areas defined by the upper and lower contours. Transect lengths at depth (Table 1) were calculated following the method described by Rutherford et al. (1986). Both stratum area and transect length at depth are parameters used to assess fish abundance.

Hydroacoustic assessments

Hydroacoustic assessment techniques were used to estimate the abundance of kokanee in Cowichan Lake. A total of five assessment surveys were carried out between November 1984 and August 1987 (Table 2). The hydroacoustic equipment consisted of an uncalibrated 70 khz Simrad EYM echosounder equipped with a time varied gain circuit and a narrow beam (11°)

transducer. The operating characteristics of an uncalibrated echosounder have been described by Gjernes et al. (1986). The transducer was fastened to the side of the survey boat and suspended at a depth of one metre below the lake surface. The transducer location allowed for depths of greater than 2 m to be insonified.

Assessment surveys were conducted during darkness along seven preset transect locations (Fig. 3). Start and end points were located using radar. Standard hydroacoustic procedures were followed when echosounding along transects (Hyatt et al. 1984). Population estimates were determined by echo trace counting and calculated using the formula recommended by Hyatt et al. (1988).

Fish sample collection

Fish were collected from Cowichan Lake to determine species composition of hydroacoustic targets and to provide data on age, sex, size and characteristics useful for stock identification (parasite prevalence and biochemical genetic data). Several gear types were employed to obtain representative samples from depths ranging from 0-60 m. Live samples were collected for salt water tolerance tests and to determine the feasibility of collecting large numbers (>10,000) of live kokanee for mark-recapture studies.

Midwater trawl gear was fished in conjunction with the hydroacoustic assessment surveys. A 2 X 2 X 7.5-m trawl net was used for all the surveys except for the January 1985 and March 1986 surveys in which a 3 X 3 X 8.5-m net was used. The trawl net and towline configurations were identical to those outlined by Gjernes (1979) except that we used a 7-m fiberglass boat equipped with a 3.5-hp gas-powered trawl winch. Both trawl nets were constructed of a graded series of mesh ranging from 5.0 cm at the mouth to 1.3 cm. A 350-µm mesh net in the codend created a dead water space to protect fish from scale loss while in the net. On each survey, four to eight trawls were made at various depths depending on target density. A minimum of one surface trawl was carried out on each survey to determine whether fish were present in the surface layer which was not insonified due to the configuration of the echosounding equipment.

Purse seining was carried out between March 26 and April 7, 1987 using the 10-m fisheries research vessel M.V. TAHLOK equipped with a 210 X 22-m seine net with a mesh size ranging from 38 mm in the wing 6 mm in the bunt. A 190-L fiberglass tank with circulating lake water was installed on the vessel to hold live samples. Fish were held in this tank for a maximum of 6 h before being transferred to a 800-L insulated transport tank supplied with an oxygen flow, and trucked to holding facilities at the Pacific Biological Station. Transportation time was less than 2 h.

Spawning ground surveys

Surveys for spawning kokanee were carried out on selected streams and beaches of Cowichan Lake. A foot survey was undertaken by a three man crew on September 26 and October 16, 1984 on Robertson River, Mesachie, Sutton, Nixon and Shaw Creek from the mouths to a point 500 m upstream. Three

sites were surveyed by boat on December 19, 1986: 1) the mouth of McKay Creek; 2) the mouth of Nixon Creek; and 3) Gordon Bay Beach (Fig. 3). A 2.5-cm monofilament gillnet was set perpendicular to the shore at the mouth of McKay creek at 12:50 December 19, 1986 and retrieved at 15:30 the same day. The shoreline along the head and north side of the north arm, the north shore of the south arm, the head of the west arm, and Gordon Bay were surveyed for spawning kokanee on December 17, 1987.

Sex and age determination

Sex was determined by visual inspection of the gonads for fish larger than 80 mm. For fish less than 80 mm, gonads were pressed between glass slides and examined microscopically at 50 X magnification for the presence or absence of ova.

Age was determined by length frequency plots, scales and occasionally from the surface of otoliths as described by Bilton and Jenkinson (1968) using ageing criteria developed for anadromous sockeye salmon.

Electrophoretic analysis

Kokanee tissues were stored at approximately -40°C and later analyzed by horizontal starch gel electrophoresis as described by Utter et al. (1984). Electrophoretic variation was assayed at 23 loci (Table 3) which exhibit simple Mendelian segregation. Following Allendorf and Utter (1979), alleles at polymorphic loci were designated according to their relative mobility starting with the allele exhibiting the least anodal migration; the most common allele was designated type 100.

Allele frequencies were computed by summing alleles across all (n) genotypes and dividing by the total number of alleles (2n). Genotype frequencies at each locus were examined for departure from Hardy-Weinberg equilibrium by chi-square. A dendrogram was constructed using unbiased genetic identities (Nei 1978) and the unweighted pair group method (Sneath and Sokal 1973) to compare the genetic similarity of kokanee in Cowichan Lake and anadromous sockeye in neighbouring lake systems.

Parasitological analysis

Brains were examined for the presence of the myxosporean parasite Myxobolus neurobius following the method recommended by L. Margolis (Pacific Biological Station, Nanaimo, B.C., V9R 5K6). This procedure involves digestion of the brain in a pepsin-hydrochloric acid solution and microscopic examination of the sediment following centrifugation. Parasite prevalence refers to the proportion of brain samples carrying the parasite. The intensity of infection within individual fish was not evaluated.

Seawater challenge

Kokanee that had survived for at least 16 d in tanks at the Pacific

Biological Station following capture were subjected to a seawater challenge to determine their osmoregulatory capability. These included 30 kokanee collected by purse seine on April 7, 1987 and maintained for 16 d at a water temperature of 9°C under natural photoperiod, and a single surviving specimen collected by midwater trawl on October 7, 1985 and maintained for 23 d at a water temperature of 10°C and a photoperiod giving 16 h of daylight. The fish were exposed to seawater with a salinity of 28°/.. for 24 h and then killed to obtain plasma samples from which sodium concentrations were determined. Plasma sodium concentrations provide an index of osmoregulatory ability since sodium chloride is the major osmotic component of the extracellular fluid (Clarke and Blackburn 1977). These tests were carried out following procedures described by Blackburn and Clarke (1987).

RESULTS

Abundance of juvenile kokanee

Annual population estimates were obtained for Cowichan Lake in 4 yr, 1984-1987. The November 1984 estimate was based on two cross-lake transects whereas the remaining three estimates were based on 7 transects. Over the four year period, kokanee population estimates ranged from a high of 5.11 million fish in 1984 to a low of 3.4 million fish in 1986; fish densities were 540 fish/ha and 822 fish/ha, respectively. These annual population estimates include all age classes except spawning fish. The relative abundance of the individual age classes (Table 4) was estimated from trawl catch data. Age 0+ kokanee were numerically dominant in 1984 and this cohort remained dominant as age 1+ juveniles in 1985. A similar trend did not occur in subsequent years and age 0+ fish were numerically dominant in both 1986 and 1987.

Juvenile kokanee were distributed vertically from a depth of 70 m to the lake surface. However, on all surveys the greatest concentration of fish occurred between 15 m and 30 m (Fig. 4). Hydroacoustic estimates of fish density were not reliable for depths less than 3 m owing to the relatively small area insonified. Surface trawls caught very few fish (Table 5) and consequently we inferred that relatively few juveniles were present near the surface. Juvenile kokanee were predominant in mid-water trawl catches. The combined total catch in all four surveys was 445 kokanee and and 1 lamprey (Lampetra macrostoma). No other species were caught in the midwater trawl.

Fish collections and survival rates

A total of 633 kokanee were caught in 18 seine sets between March 26, and April 7, 1987. Catches ranged from 0 to 350 fish/set (Table 6). The combined total catch for species other than kokanee was 5 threespine stickleback (Gasterosteus aculeatus), 2 lamprey and 2 rainbow trout.

Most kokanee (85%) survived capture by seine and the 6-h holding period in the live tank aboard the M.V. TAHLOK. Only 9% survived the initial 24 h following capture regardless of whether fish were held in holding

pens in Cowichan Lake or transported to holding tanks at the Pacific Biological Station. Of those surviving after 24 h, 30% and 76% died over the next 5 and 15 d, respectively. After the latter period, most deaths were attributed to fungal infections associated with descaling during capture.

Age composition, length distribution and sex ratio

Age composition varied with gear type fished. The age composition of trawl caught kokanee showed a trend in 1984 and 1985. The pooled 1984 samples consisted predominately (84%) of age 0+ kokanee (1983 brood year). This cohort maintained its dominance in the 1985 catches and as a result 70% of the 1985 samples consisted of age 1+ fish. However in 1986 the age 0+ cohort was again numerically dominant (72%) (Table 5). From March-April 1987 only 13% of the kokanee caught by seine were age 1+ (most were 2+), whereas trawl catches during the same period for the 0 to 20 m stratum consisted of 93% age 1+ kokanee (Table 6). All four kokanee collected from spawning sites in 1987 were age 3.

Males were more numerous than females in all five samples (Table 7) which suggests a significant male bias in sex ratio among juveniles ($p<0.05$, sign test). Within samples, the bias was statistically significant only in the March 6, 1985 sample which consisted entirely of age 1+ fish. It is possible that some females were mistakenly recorded as males owing to the immaturity of this age class. However, no general relationship between age and sex ratio was apparent in the other samples.

There was no obvious difference in size between sexes for any of the age groups (Fig. 5). The mean lengths of the 0+ age class from the November 28, 1984, October 7, 1985 and October 28, 1986 samples were 61.17, 59.00 and 53.39 mm, respectively. Mean lengths for the 1+ age class for the same periods were 126.81, 122.38 and 129.62 mm, respectively. Age 2+ kokanee at a mean length of 153.50 and 156.50 mm, respectively, were caught only in the 1985 and 1986 fall surveys. The largest kokanee observed were the seven spawned-out carcasses which ranged from 163 to 172 mm. Growth rates for 1984, 1985 and 1986 cohorts are shown in Figure 6.

Spawning distribution

No spawning or spawned-out kokanee were observed during the October 16, 1984 survey of Mesachie, Robertson, Sutton, Nixon or Shaw creeks although fifteen coho and three dolly varden were observed in the lower reaches of Nixon Creek. Three spawned-out kokanee were collected on December 19, 1986 along the beaches of Cowichan Lake at the mouth of McKay Creek and in Gordon Bay. Live kokanee were also observed along the shoreline at these sites but no fish were captured in 2.5-cm mesh gillnets during a 12-h set. One hundred and thirty-five spawned-out kokanee were observed December 12, 1982 along the beach at the head of the north arm of Cowichan Lake (Ted Burns, P.O. Box 343, Lake Cowichan, B.C., pers. comm.). Four spawned-out kokanee were collected on December 17, 1987; three fish were retrieved from the beach on the north shore of the south arm and one carcass was collected along the north shore of the north arm.

Electrophoretic variation

Five of the 23 loci assayed by electrophoresis were polymorphic to the extent that the common (100) allele frequencies were less than 0.99 (Table 8). Average heterozygosity over all loci was 0.036 for the Cowichan Lake kokanee sampled. None of the observed genotypic frequencies were statistically different from the expected Hardy-Weinberg genotypic frequencies (χ^2, $p>0.92$, 1 df). The most polymorphic loci were PGM-1, PGM-2, ADA-2, PGI-1, and AAT-3. The Cowichan Lake kokanee population was more similar to the neighbouring Cheewhat Lake sockeye population than to other Vancouver Island sockeye stocks assayed at these loci (Quinn et al. 1987; B. E. Riddell and C. C. Wood, Pacific Biological Station, Nanaimo, B.C., V9R 5K6, unpubl. data) (Fig. 7).

Parasite prevalence

All 100 age 2+ fish sampled were infected with the brain parasite Myxobolus neurobius. However, only 4.0% of the 69 age 1+ fish sampled were infected. This result is consistent with other studies that indicate parasite prevalence is correlated with freshwater age (Wood et al. 1987; Quinn et al. 1987, L. Margolis, Pacific Biological Station, Nanaimo, V9R 5K6, pers. comm.; and D. A. Moles, Auke Bay Laboratory, P.O. Box 155, Auke Bay, AK 99821, pers. comm.).

Salt water tolerance

Unfortunately, all 82 kokanee approaching the age at which typical anadromous sockeye would smolt (age 1+) died before their osmoregulatory ability could be tested. However, age 2+ kokanee (mean weight 26.1 g, SD=5.2) showed some ability to osmoregulate in sea water. After 24 hours exposure to 28°/.. seawater, plasma sodium concentrations averaged 198 mmol/L and ranged from 172-258 mmol/ L for 26 fish captured on April 7, 1987 and tested 16 days later. The single age 2+ kokanee (weight=31.9 g) collected on October 7, 1985 and tested October 31, 1985 fared better with a plasma sodium concentration of only 174 mmol/L. This fish was a female carrying eggs that probably would have spawned in December of the same year. Smolting salmon typically exhibit plasma sodium values around 160-170 mmol/L (Blackburn and Clarke 1987).

DISCUSSION

These survey results indicate that kokanee are abundant in Cowichan Lake and are by far the most numerous fish species in the limnetic zone. Best estimates range between 3.4 and 5.1 million juveniles during 1984 - 1987. However, the observed densities (540 - 822 fish/ha) are not high in comparison to juvenile sockeye densities in other Vancouver Island lakes which are typically 600 - 2500 fish/ha (Hyatt and Stockner 1985). Also, similar hydroacoustic surveys conducted by the authors on Second Lake in the Nanaimo

River system on April 16, 1986 revealed that kokanee densities there were on the order of 403 fish/ha although the total population was much smaller than for Cowichan Lake owing to the smaller size of the lake; very few kokanee were observed in First Lake in that system.

Population estimates from hydroacoustic surveys using the procedures outlined in this study are considered to be unbiased except where a significant proportion of the fish population occurs above 10 m (K. D. Hyatt, Pacific Biological Station, Nanaimo, B.C., V9R 5K6, pers. comm.). Confidence intervals for the estimates are derived by considering the variation in fish density from one transect to another, and therefore, precision depends on how many transects are surveyed. Very few kokanee were caught in midwater trawls less than 10 m deep and it seems very unlikely that many kokanee escaped detection near the surface while the lake was stratified and surface temperatures exceeded 18°C. During the March - April surveys in 1987, significant numbers of kokanee (mostly age 1+ and 2+) were taken by seine net shallower than 18 m but none were taken by midwater trawl at the surface. It seems likely that the midwater trawl is less effective than the seine at catching fish near the surface, especially larger fish, due to higher light intensities and perhaps due to disturbance from the boat's wake. Even so, a few kokanee were taken at the surface by midwater trawl in the November surveys and we are confident that more kokanee would have been captured had they been abundant in the surface layers.

The size composition data from the midwater trawl catches should be interpreted with caution. Although the midwater trawl gear is capable of catching all sizes of kokanee or sockeye from newly emerged fry to spawning adults (Hyatt and Stockner 1985), it seems probable that larger fish are better able to evade capture especially near the surface where higher light intensities would make the net more visible. Certainly seine catches in March - April, 1987 contained a far higher proportion of age 1+ and 2+ kokanee than did midwater trawl catches during the same time period. It is also possible that small kokanee escaped through the 38-mm meshes on the wing of the seine net. In any event, the discrepancies in size composition of catches by the different nets demonstrate that the size composition data are only useful for qualitative comparisons. For example, the variations in population density between 1984 and 1987 can be attributed to variation in year-class strength where the spawning populations in 1983 and 1986 produced relatively strong recruitments of fry to the lake. Thus, there is some suggestion of a 3-yr cycle in abundance associated with maturation at age 3.

Males were more numerous than females but within samples, the difference was statistically significant for only one age 1+ sample. A simple explanation for this observed male bias is that errors were made in determining the sex of some immature specimens. Developing ova may have gone undetected in small, poorly-preserved specimens which would result in a male-biased estimate of sex ratio. However, it is unlikely that errors in sex determination account for the significant male bias observed among samples that include older age groups. Furthermore, there is no indication that estimates of sex ratio are more biased for age 1+ fish than for older fish in samples other than the March 6, 1985 sample. Thus, we believe that the observed differences in sex ratio are real, perhaps resulting from differences in depth distribution or vulnerability to the sampling gear.

Kokanee in Cowichan Lake spawn later in the year than is reported for other kokanee populations in British Columbia (Seeley and McCrammon 1966). Surface water temperatures at the time of spawning (December) were approximately 7°C. The vast majority of kokanee in Cowichan Lake probably spawn in upwelling areas along the margins of the lake such as those reported in this study. To our knowledge, no kokanee have been observed to spawn in the tributaries to Cowichan Lake. Assuming an average fecundity of 250 eggs per female (as for Meadow Creek kokanee, Hutchinson 1984) and an egg-to-fry survival of 10% (typical of other sockeye populations, Foerster 1968), we conclude that the total spawning population in Cowichan Lake exceeds 150 thousand in most years. To date, this resource appears to be relatively unexploited.

Cowichan Lake is the second largest lake on Vancouver Island and there may be opportunities to better utilize this kokanee population -- either by enhancing conditions for growth in the lake or alternatively, by establishing an anadromous sockeye salmon run to the lake. Unfortunately, an experiment to evaluate the potential for creating "sea-run kokanee" by marking wild juvenile kokanee with coded-wire tags and forcing their downstream migration could not be completed due to extremely poor survival of wild juveniles captured by seine. However, it has been established that underyearling kokanee raised in a hatchery exhibit the same osmoregulatory ability as sockeye salmon raised under the same conditions (C. J. Foote, C. C. Wood, W. C. Clarke, and J. Blackburn, Pacific Biological Station, Nanaimo, B.C., V9R 5K6 unpubl. data). Furthermore, older or pre-spawning kokanee captured from the wild displayed some ability to tolerate seawater. It is possible that the osmoregulatory performance of these fish would have been better had they not been stressed during capture; as it was, more than 75% of those collected died before exposure to seawater. Thus, there appears to be no physiological barrier to anadromous behaviour in kokanee.

Hatchery-raised kokanee forced to migrate downstream from Cultus Lake survived to be caught in the commercial fishery as maturing adults in their fifth year and some are thought to have returned to Cultus Lake (Foerster 1947). Although we were unable to repeat this study with wild kokanee, it may be worthwhile to repeat the experiment using Cowichan Lake kokanee raised under hatchery conditions prior to marking and forcing migration. An anadromous sockeye run to a lake the size of Cowichan Lake would be a valuable resource and further research on this problem seems warranted.

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Table 1. Transect lengths and area at depth for Cowichan Lake, B.C.

Depth stratum (m)	Stratum area (ha)	Length (m) of transect #1	#2	#3	#4	#5	#6	#7
surface	6360	1840	2560	1820	2550	2570	1140	840
0-5	6222	1840	2560	1820	2550	2570	1140	840
5-10	5944	1840	2560	1820	2429	2471	1140	773
10-15	5667	1840	2324	1801	2111	2341	1140	732
15-20	5389	1799	2257	1777	1710	2238	1123	715
20-30	4970	1714	2149	1767	1396	1977	1089	682
30-40	4408	1625	1953	1738	918	1820	1041	640
40-50	3731	1312	1455	1647	749	1694	1003	541
50-60	2937	609	1151	1527	266	1550	951	499

Table 2. Summary of Cowichan Lake Assessment Survey.

Year	Date	Type of Survey Conducted			
		Hydroacoustic assessment	Trawl	Seine	Spawning ground
1984	Sept. 20				X
	Oct. 16				X
	Nov. 28	X	X		
1985	March 6		X		
	Oct. 7-17	X	X		
1986	Oct. 28	X	X		
	Dec. 19				X
1987	March 26			X	
	March 30-31		X		
	April 2-3			X	
	April 7			X	
	Aug. 26	X	X		
	Dec. 17				X

Table 3. Enzyme and tissues used to investigate genetic variation in Oncorhynchus nerka. Buffers used were (AC) an amine citrate buffer described by Clayton and Tretiak (1972), and (RW) a Tris, citric acid, lithium hydroxide, and boric acid buffer described by Ridgway et al. (1970).

Enzyme	Tissue	Locus	Buffer
Aspartate aminotransferase	Heart	AAT-1,2	AC
	Eye	AAT-3	AC
Aconitase	Liver	ACON-3	AC
Adenosine deaminase	Muscle	ADA-2	AC
a-Glycerophosphate dehydrogenase	Muscle	AGP-1	AC
Glyceraldehyde-phosphate dehydrogenase	Eye	GAP-4,5	AC
Isocitrate dehydrogenase	Muscle	IDH-1,2	AC
	Liver	IDH-3,4	AC
	Eye	IDH-3,4	AC
Lactate dehydrogenase	Muscle	LDH-1,2	RW,AC
	Heart	LDH-3	AC
	Liver	LDH-4	RW
	Eye	LDH-5	RW
Malate dehydrogenase	Liver	MDH-1,2	AC
	Muscle	MDH-3,4	AC
Malic enzyme	Muscle	ME-1,3	AC
Phosphoglucoisomerase	Muscle	PGI-1,2,3	RW
Phosphoglucomutase	Heart	PGM-1	AC
	Muscle	PGM-2	RW
Phosphomannoisomerase	Heart	PMI	AC
Tetrazoliumoxidase	Muscle	TO	RW
6-Phosphogluconate dehydrogenase	Muscle	6-PG	AC

Table 4. Population and density estimates of Cowichan Lake kokanee 1984-1987. Confidence intervals (±95%) are shown in parentheses. Age calculated from December of brood year.

Year	Date	Total Population Number millions	Total Population Density fish/ha	Age 0+ Number millions	Age 0+ Density fish/ha	Age 1+ Number millions	Age 1+ Density fish/ha	Age 2+ Number millions	Age 2+ Density fish/ha
1984	Nov. 28	5.116 (1.608)	822.3 (258.4)	4.318	690.7	0.798	131.6	—	—
1985	Oct. 7	3.630 (1.177)	583.5 (189.2)	1.452	233.4	1.815	291.7	0.363	58.3
1986	Oct. 28	3.363 (0.820)	540.6 (131.8)	2.429	390.4	0.934	149.6	—	—
1987	Aug. 26	5.031 (1.915)	808.6 (307.8)	5.009	805.0	0.022	3.5	—	—

Table 5. Summary of midwater trawl catches by date, depth, and age class.

Year	Date	Trawl No.	Duration (min)	Depth (m)	Trawl net size	Number of kokanee	Kokanee catch by age 0+	1+	2+
1984	Nov. 28	1		23	2X2	12	6	6	0
		2		35		74	69	5	0
		3		20		23	17	6	0
						109	92	17	0
1985	Oct. 07	1	15	25	2X2	5	0	4	1
		2	15	30		1	0	1	0
		3	15	28		4	4	0	0
						10	4	5	1
1985	Oct. 17	1	15	22	3X3	8	0	8	0
		2	15	26		8	1	6	1
		3	15	25		14	6	8	0
		4	15	22		11	4	7	0
		5	5	22		5	1	4	0
		6	15	15		3	1	2	0
		7	15	25		7	0	7	0
		8	15	25		14	6	8	0
		9	15	33		11	3	8	0
		10	15	0		5	2	3	0
						86	24	61	1
1986	Oct. 28	1	35	20	2X2	12	12	0	0
		2	35	30		1	1	0	0
		3	30	35		23	13	10	0
		4	33	0		0	0	0	0
						36	26	10	0
1987	Mar. 30-31	1	30	0	2X2	3	1	2	0
			30	15		10	0	10	0
			30	30		6	0	6	0
			30	30		11	0	11	0
			30	15		1	0	1	0
			30	0		0	0	0	0
						31	1	30	0

Table 5 (cont'd)

Year	Date	Trawl No.	Duration (min)	Depth (m)	Trawl net size	Number of kokanee	Kokanee catch by age 0+	1+	2+
1987	Aug. 26	1	30	20	2X2	104	104	0	0
		2	30	15		70	69	1	0
		3	30	30		12	12	0	0
		4	30	0		0	0	0	0
		5	30	0		0	0	0	0
		6	30	15		0	0	0	0
		7	30	30		18	18	0	0
						204	203	1	0

Table 6. Summary of seine catches by set, date and age class.

Year	Date	Time	Total number of kokanee	Kokanee catch by age class 0+	1+	2+	Other
1987	Mar. 26	16:00	1	0	1	0	1 rainbow trout
		17:00	350	0	0	350	
		18:00	11	0	1	10	
1987	Apr. 02	17:30	0	0	0	0	
		19:30	25	0	2	23	1 lamprey
		21:30	17	0	5	12	
		22:30	17	0	10	7	1 stickleback
		23:00	17	0	5	12	
		23:45	26	0	9	17	1 stickleback
1987	Apr. 03	02:30	16	0	1	15	1 stickleback
		03:00	14	0	2	12	
		03:30	13	0	2	11	
		04:15	25	0	5	20	2 sticklebacks
		04:45	21	0	2	19	
		06:15	1	0	1	0	1 rainbow trout
1987	Apr. 07	18:00	10	0	0	10	
		20:30	35	0	22	13	
		21:30	34	0	14	20	1 lamprey
Totals			633	0	82	551	

Table 7. Sex composition by age, for kokanee sampled from Cowichan, B.C.

Year	Date	Age class	Number sampled	Number of males	Proportion males	Probability of equal sex ratio (χ^2 test)
1985	Mar. 6	1+	69	51	0.74	P<0.001
1985	Oct. 7-17	0+	11	8	0.73	P>0.10
		1+	63	36	0.57	P>0.25
		2+	3	3	1.00	P>0.05
		All ages	77	47	0.61	P>0.05
1986	Oct. 28	0+	27	17	0.63	P>0.10
		1+	8	3	0.38	P>0.25
		2+	2	2	1.00	P>0.10
		All ages	37	22	0.59	P>0.10
1987	Mar. 26	2+	256	136	0.53	P>0.10
1987	Aug. 26	0+	197	106	0.54	P>0.25

Table 8. Summary of allele frequencies by locus. Unpublished data for populations 2-7 from C. C. Wood and B. E. Riddell, Pacific Biological Station, Nanaimo, B.C., V9R 5K6.

	POPULATION[1]						
LOCUS	1	2	3	4	5	6	7
PGM-1							
(N)	150	100	111	138	89	132	100
100	0.460	0.375	0.239	0.036	0.039	0.383	0.100
NULL	0.540	0.625	0.761	0.964	0.961	0.617	0.900
PGM-2							
(N)	150	100	136	149	89	182	100
100	0.840	0.865	0.879	0.977	0.978	0.799	0.990
120	0.160	0.135	0.121	0.023	0.022	0.201	0.010
IDH-3							
(N)	148	99	143	154	91	183	98
100	1.000	1.000	1.000	1.000	1.000	0.984	1.000
85	0.000	0.000	0.000	0.000	0.000	0.016	0.000
LDH-4							
(N)	150	100	143	154	91	183	100
100	1.000	1.000	1.000	1.000	1.000	0.997	1.000
115	0.000	0.000	0.000	0.000	0.000	0.003	0.000
AAT1,2[2]							
(N)	149	100	0	0	91	0	98
100	1.000	1.000			1.000		1.000
MDH3,4[2]							
(N)	150	99	143	154	91	180	100
100	1.000	0.995	0.976	0.968	1.000	0.992	0.995
120	0.000	0.005	0.024	0.032	0.000	0.008	0.005
AGP-1							
(N)	149	99	136	154	91	183	98
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 8 (cont'd)

LOCUS	POPULATION[1] 1	2	3	4	5	6	7
ADA-2							
(N)	144	99	0	0	91	0	50
100	0.990	1.000			1.000		1.000
92	0.010	0.000			0.000		0.000
ME-1							
(N)	149	99	136	154	91	183	100
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000
P6G							
(N)	150	99	136	104	91	183	100
100	1.000	1.000	0.915	1.000	1.000	0.850	0.985
94	0.000	0.000	0.085	0.000	0.000	0.150	0.015
IDH1,2[2]							
(N)	148	99	0	0	91	0	100
100	1.000	1.000			1.000		1.000
PGI-1							
(N)	150	99	76	111	90	128	98
100	0.997	1.000	1.000	0.986	1.000	1.000	1.000
65	0.003	0.000	0.000	0.014	0.000	0.000	0.000
LDH1,2[2]							
(N)	148	100	0	0	91	0	100
100	1.000	1.000			1.000		1.000
ACON3							
(N)	149	100	0	0	91	0	100
100	1.000	1.000			1.000		1.000
MDH1,2[2]							
(N)	150	100	143	154	91	183	100
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SDH-L							
(N)	150	96	0	0	91	0	0
100	1.000	1.000			1.000		

Table 8 (cont'd)

	POPULATION[1]						
LOCUS	1	2	3	4	5	6	7
TO							
(N)	150	100	0	0	91	0	98
100	1.000	1.000			0.995		1.000
145	0.000	0.000			0.005		0.000
IDH-4							
(N)	150	96	143	154	91	183	97
100	1.000	0.922	0.979	1.000	1.000	1.000	0.969
162	0.000	0.078	0.021	0.000	0.000	0.000	0.031
AAT-3							
(N)	150	50	0	0	90	0	95
100	0.987	1.000			1.000		1.000
117	0.013	0.000			0.000		0.000
GAP-E							
(N)	150	96	0	0	91	0	97
100	1.000	1.000			1.000		1.000
LDH-5							
(N)	150	79	143	144	90	182	0
100	1.000	1.000	1.000	1.000	1.000	1.000	
PMI-H							
(N)	145	100	92	113	91	93	100
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000
LDH-3							
(N)	150	100	114	154	91	182	99
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000

[1]Key to populations

1 = Cowichan Lk 1985
2 = Cheewhat Lk 1984
3 = Great Central Lk 1983
4 = Henderson Lk 1983
5 = Kennedy Lk 1986
6 = Sproat Lk 1983
7 = Hobiton Lk 1987

[2]Duplicated loci considered as single locus.

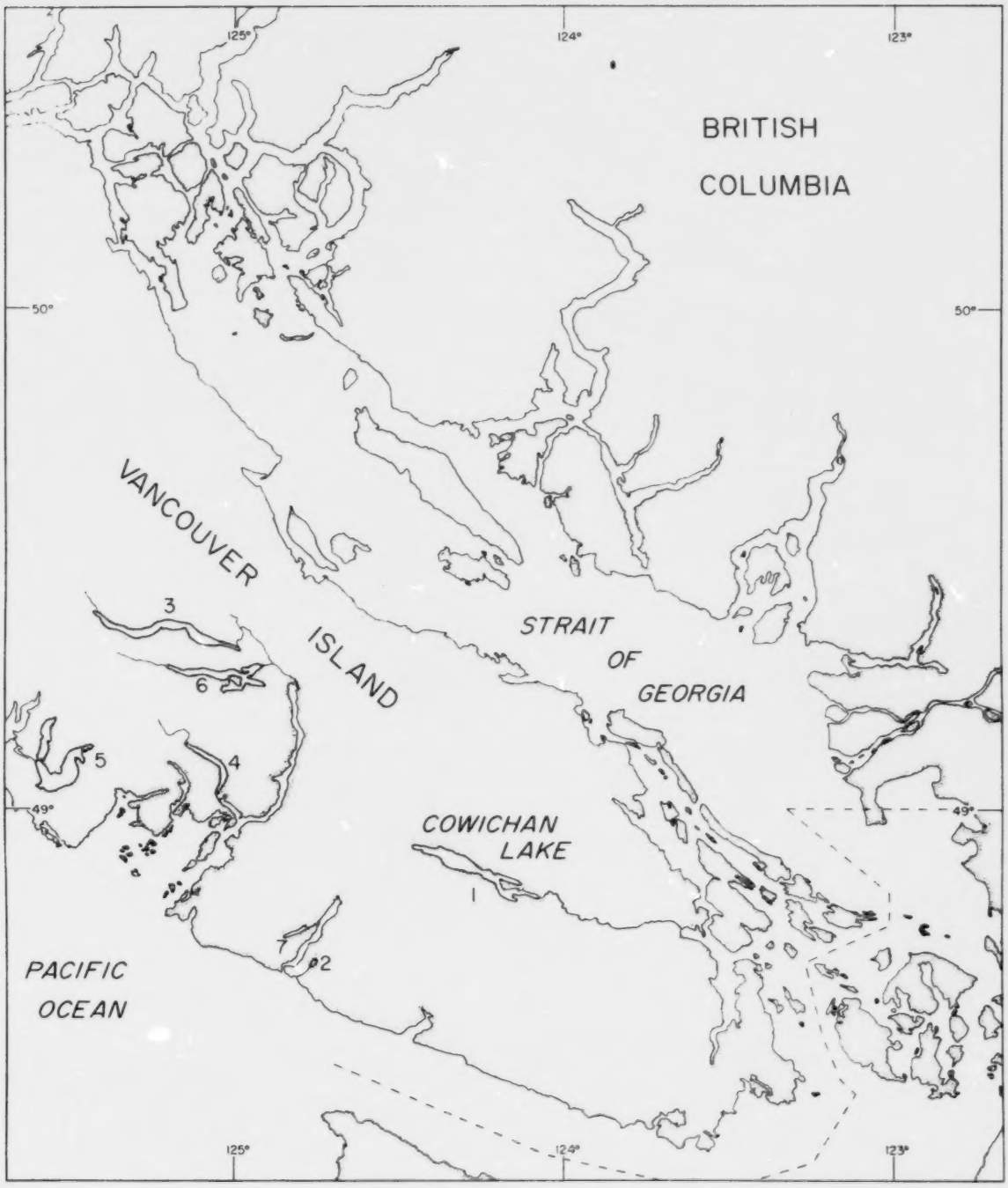

Fig. 1. Location of Cowichan Lake study area. Key to lakes:

1. Cowichan Lake
2. Cheewhat Lake
3. Great Central Lake
4. Henderson Lake
5. Kennedy Lake
6. Sproat Lake
7. Hobiton Lake

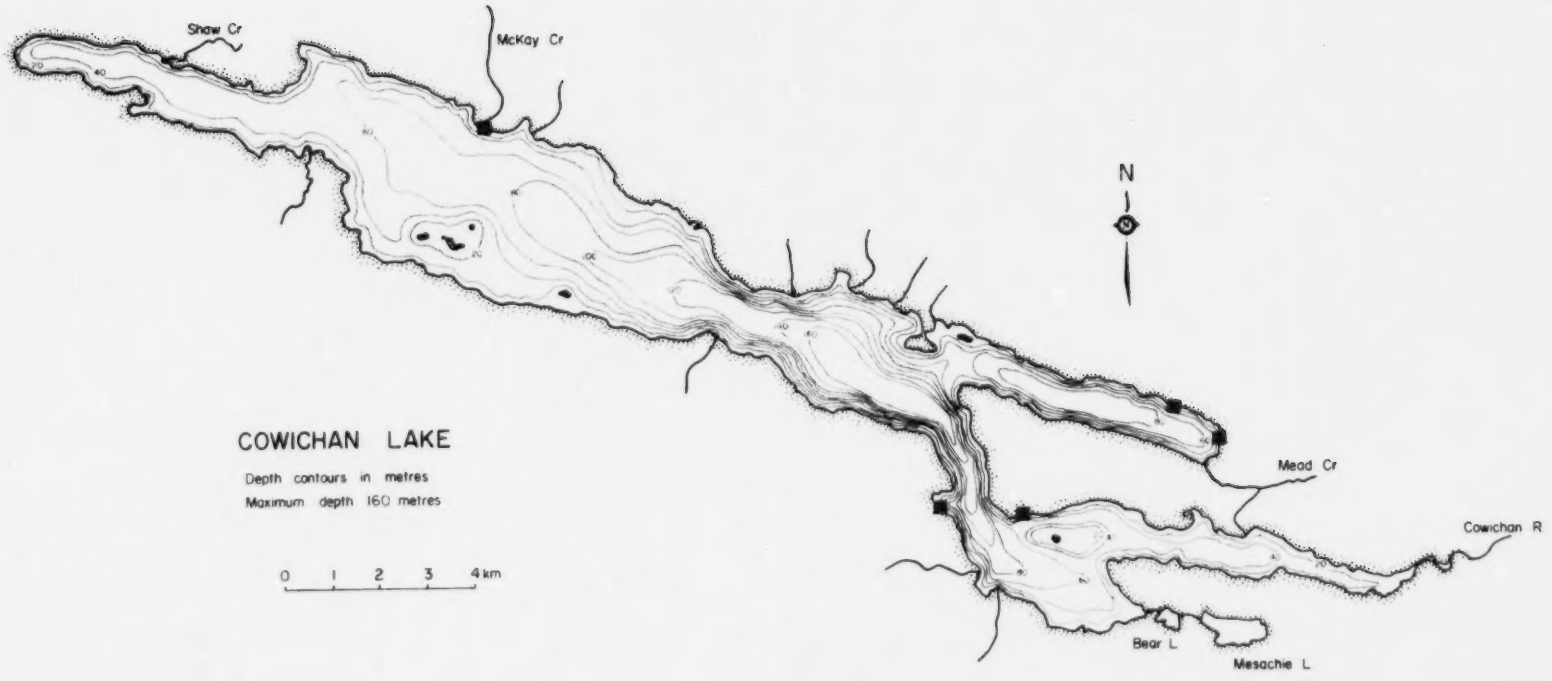

Fig. 2. Cowichan Lake bathymetry. Solid boxes show reported spawning areas.

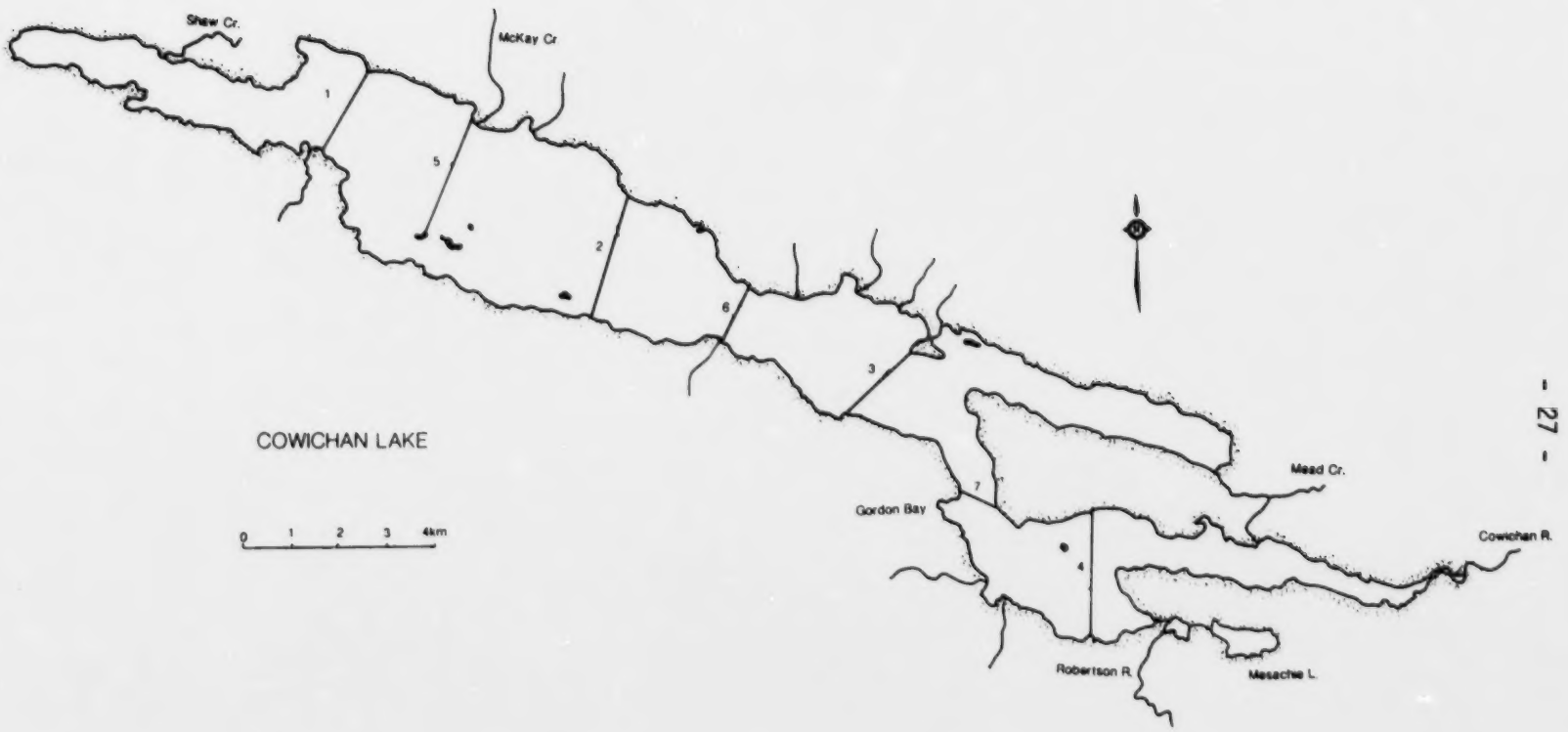

Fig. 3. Hydroacoustic transect locations on Cowichan Lake.

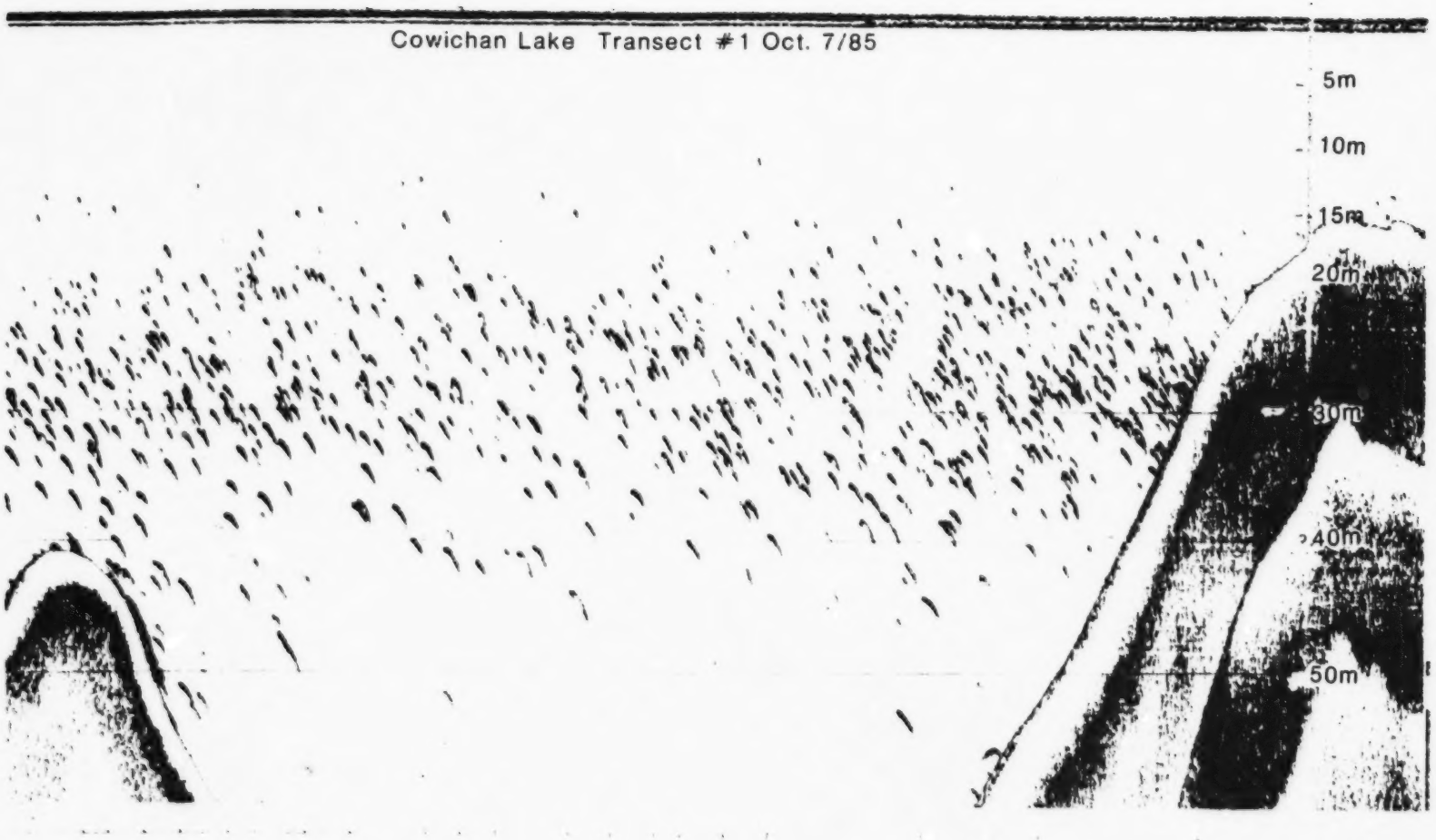

Fig. 4. Echogram from a cross-lake transect showing vertical distribution of targets.

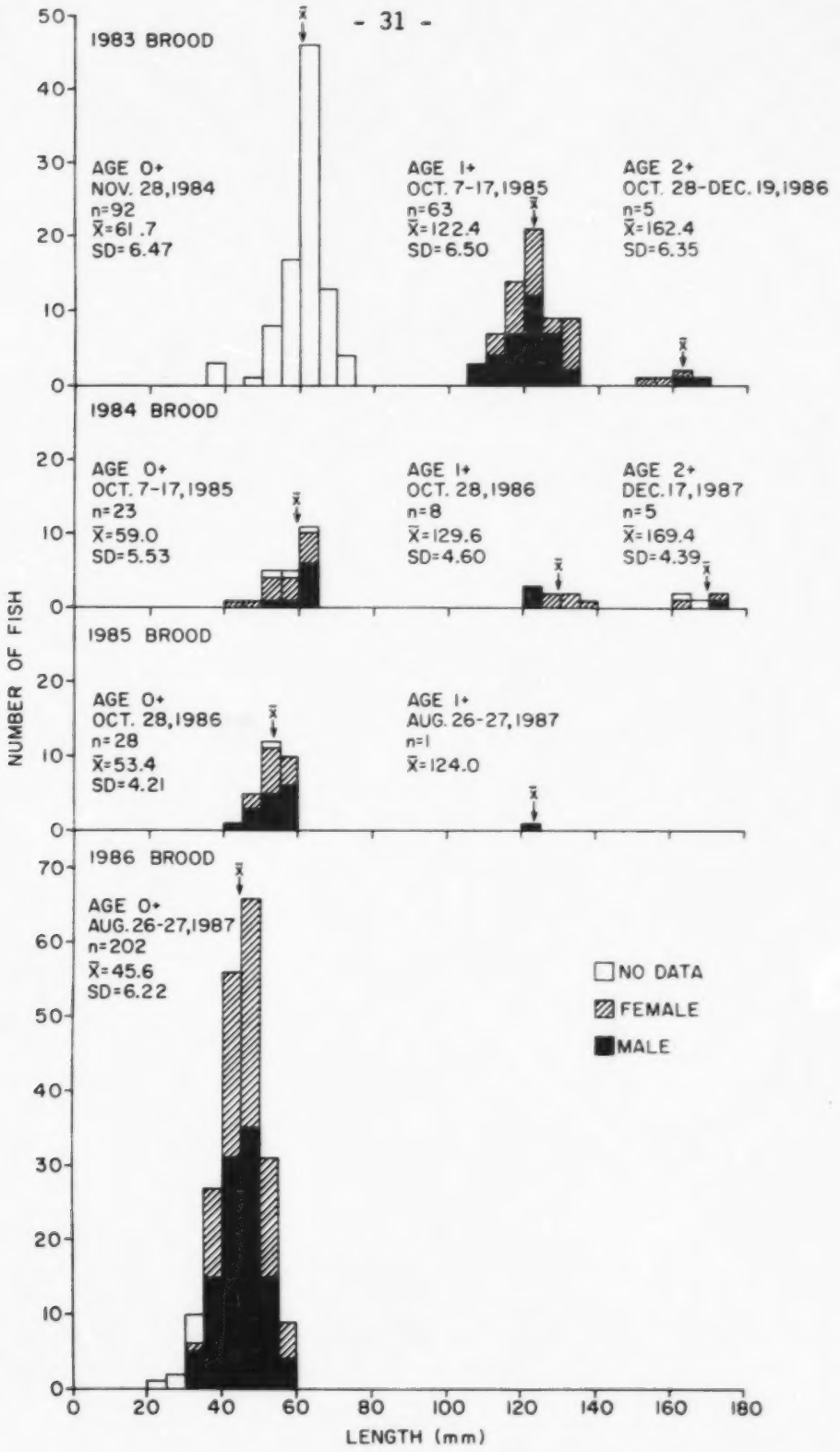

Fig. 5. Length distribution by sex and age class for kokanee collected from Cowichan Lake.

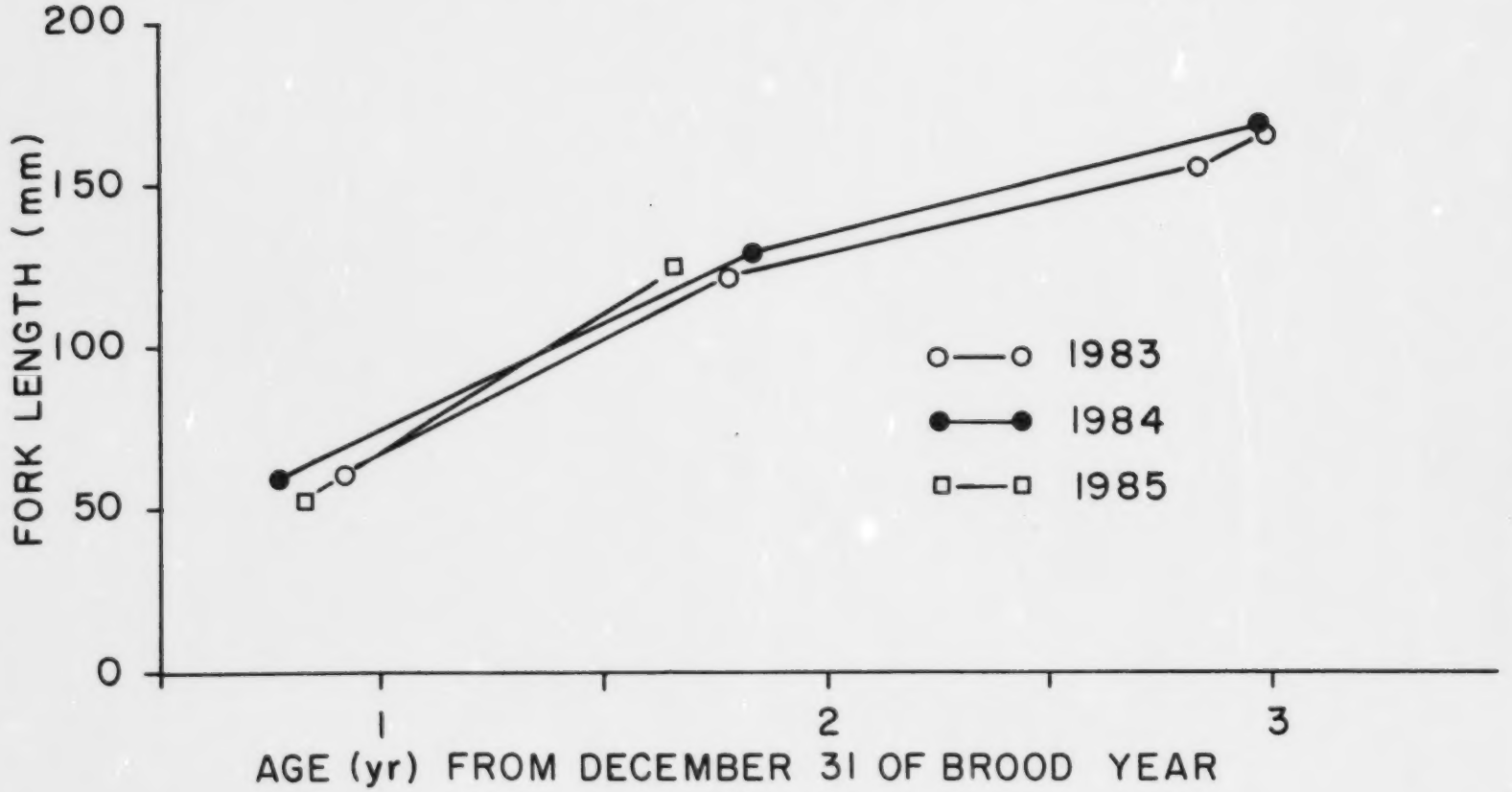

Fig. 6. Growth rate by brood year for kokanee collected from Cowichan Lake. Symbols denote mean fork length for samples shown in Fig. 5.

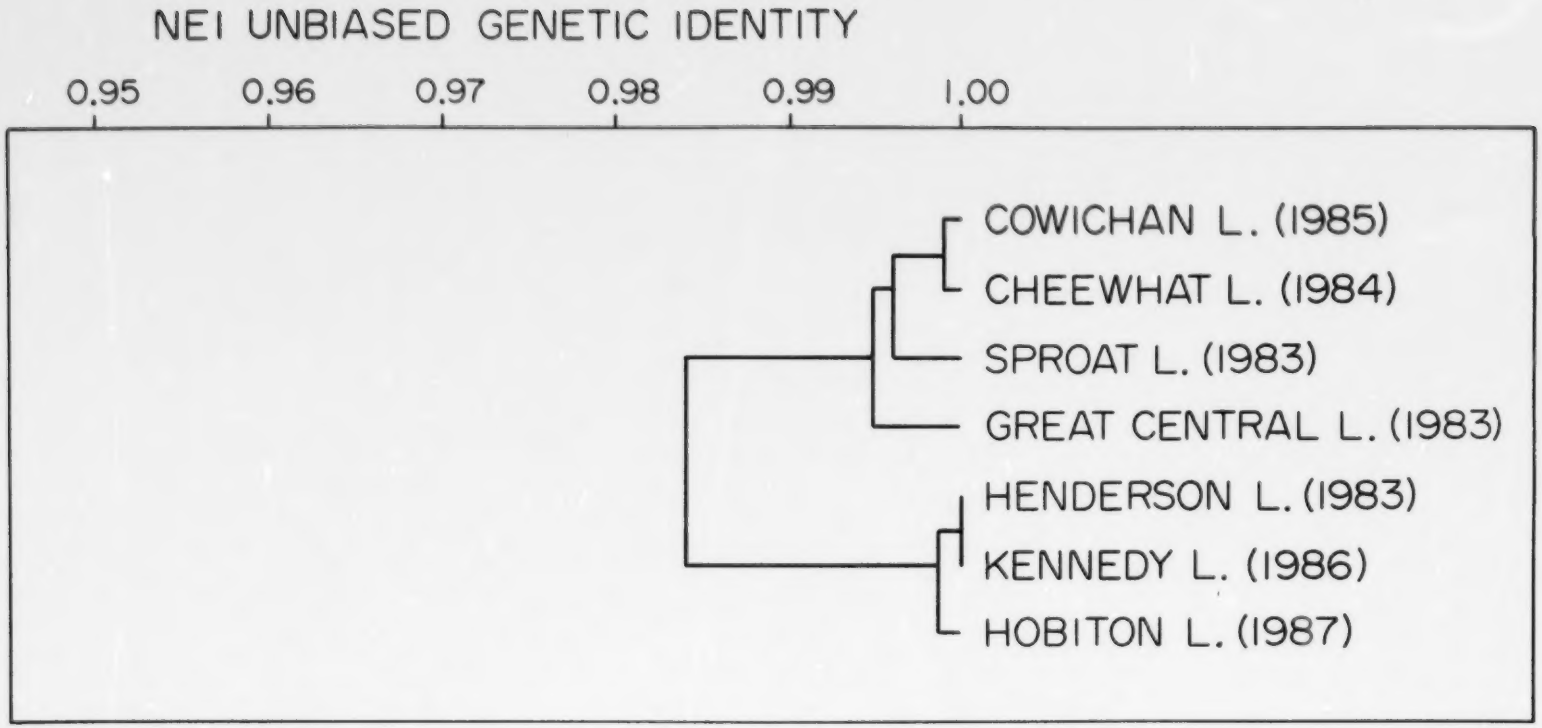

Fig. 7. Similarity dendrogram based on Nei's (1978) unbiased genetic distance for O. nerka from southern Vancouver Island lakes.